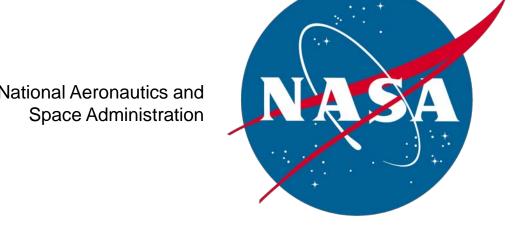
# NASA Goddard Space Flight Center's Compendium of Recent Single Event Effects Results

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Martha O'Bryan

Abstract: We present the results of single event effects (SEE) testing and analysis investigating the effects of radiation on electronics. This paper is a summary of test results.

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Table V: Summary of SEE Test Results

## Introduction

NASA spacecraft are subjected to a harsh space environment that includes exposure to various types of ionizing radiation. The performance of electronic devices in a space radiation environment are often limited by their susceptibility to single-event effects (SEE). Ground-based testing is used to evaluate candidate spacecraft electronics to determine risk to spaceflight applications. Interpreting the results of radiation testing of complex devices is challenging. Given the rapidly changing nature of technology, radiation test data are most often application-specific and adequate understanding of the

Studies discussed herein were undertaken to establish the application-specific sensitivities of candidate spacecraft and emerging electronic devices to single-event upset (SEU), single-event latchup (SEL), single-event gate rupture (SEGR), single-event burnout (SEB), and single-event transient (SET)

For total ionizing dose (TID) results, see a companion paper submitted to the 2018 Institute of Electrical and Electronics Engineers (IEEE) Nuclear and Space Radiation Effects Conference (NSREC) Radiation Effects Data Workshop (REDW) entitled "NASA Goddard Space Flight Center's Compendium of Recent Total Ionizing Dose and Displacement Damage Dose Results" by A. D. Topper, et al. [2]

## Test Techniques and Setup

(e.g. a function generator providing a pair of square wave inputs to a comparator while an oscilloscope captured the path length of the ion through the DUT and LETs available varied slightly from one monitored with the same (e.g. a memory actively writtento or read-from by an FPGA), or with an oscilloscope or Proton SEE tests were performed at logic analyzer as appropriate (e.g. a data-converter with Massachusetts General Francis H. Burr analog output channels). Occasionally a golden-chip test

Meson Facility (TRIUMF) [6]. Northwestern compared to an identical, unirradiated device and any (formerly Scripps Proton Therapy Center) [8], are highly application-dependent and may only represent Mayo Clinic [9], ProVision Center for Proton Therapy [10], and the Proton Therapy Center at Cincinnati Children's Hospital [11].

Laboratory using both Single-Photon Absorption (SPA) and Two-Photon Absorption having a wavelength of 590 nm resulting in a decreased to 1/e - or about 37% - of its intensity at the surface) of 2µm. A nominal pulse rate of 1 kHz was utilized. Pulse width was 1 ps, beam spot size ~1.2 μm.

### Table I: LBNL Test Heavy Ions Surface

lon	Energy (MeV)	LET in Si (MeV•cm²/mg) (Normal Incidence)	Range in Si (µm)
	LBNL 10 M	leV per amu tune	
<sup>18</sup> O	183	2.2	226
<sup>22</sup> Ne	216	3.5	175
<sup>40</sup> Ar	400	9.7	130
<sup>23</sup> V	508	14.6	113
<sup>65</sup> Cu	660	21.2	108
<sup>84</sup> Kr	906	30.2	113
<sup>107</sup> Ag	1039	48.2	90
<sup>124</sup> Xe	1233	58.8	90

# Table II: TAMU Test Heavy Ions

lon	Energy (MeV)	Surface LET in Si (MeV•cm²/mg) (Normal Incidence)	Range in Si (µm)
	TAMU 15 N	MeV per amu tune	
<sup>14</sup> N	210	1.3	428
<sup>20</sup> Ne	300	2.5	316
<sup>40</sup> Ar	599	7.7	229
<sup>63</sup> Cu	944	17.8	172
<sup>84</sup> Kr	1259	25.4	170
<sup>109</sup> Ag	1634	38.5	156
<sup>129</sup> Xe	1934	47.3	156
<sup>197</sup> Au	2954	80.2	155
	TAMU 25 N	MeV per amu tune	
<sup>84</sup> Kr	2081	19.8	332
<sup>139</sup> Xe	3197	38.9	286

investigator	3
Principal Investigator (PI)	Abbreviation
Melanie D. Berg	MB
Michael J. Campola	MJC
Megan C. Casey	MCC
Dakai Chen	DC
Jean-Marie Lauenstein	JML
Edward (Ted) Wilcox	TW
Edward Wyrwas	EW

## and Conventions

1963.	LET = linear energy transfer (MeV•cm²/mg)
The DUT was characterized prior-to	LET <sub>th</sub> = linear energy transfer threshold (the
ollowing irradiation, but was completely	maximum LET value at which no effect was
nmonitored during irradiation.	observed at an effective fluence of
ments, DUTs were monitored for soft	1x10 <sup>7</sup> particles/cm <sup>2</sup> – in MeV•cm <sup>2</sup> /mg)
SEUs, and for hard errors, such as	< = SEE observed at lowest tested LET
descriptions of the types of errors	> = no SEE observed at highest tested LET
•	$\sigma$ = cross section (cm <sup>2</sup> /device, unless specified a
d in the individual test reports [16], [17].	cm²/bit)
was performed using high-speed	$\sigma_{\text{maxm}}$ = cross section at maximum measured LET
ontrolled via National Instruments	(cm²/device, unless specified as cm²/bit)
Individual criteria for SETs are specific	ADC = analog-to-digital converter
application being tested. Please see the	CMOS = complementary metal oxide
orts for details [16], [17].	semiconductor
SEE sensitivity experiments include	DDR = double data rate
the linear energy transfer threshold	DUT = device under test
the inical chergy transfer threshold	ECC - arror correcting code

measurement of the linear energy transfer threshold  $(LET_{th})$  and cross section at the maximum measured LET. The LET<sub>th</sub> is defined as the maximum LET value at which no effect was observed at an effective fluence of 1×10<sup>7</sup> particles/cm<sup>2</sup>. In the case where events are observed at the smallest LET tested, LET<sub>th</sub> will either be reported as less than the lowest measured LET or determined approximately as the LET<sub>th</sub> parameter from a Weibull fit. measurements are made of the SEGR or SEB threshold V<sub>ds</sub> (drain-to-source voltage) as a function of LET and ion

Static/Biased - The DUT was provided basic power

and configuration information (where applicable), but not

may or may not have been actively monitored during

# 2) SEE Testing - Proton:

LabVIEW®. [19].

to the device and a

individual test repo

Proton SEE tests were performed in a manner similar
to heavy ion exposures. However, because protons
usually cause SEE via indirect ionization of recoi
particles, results are parameterized in terms of protor
energy rather than LET. Because such proton-induced
nuclear interactions are rare, proton tests also feature
higher cumulative fluences and particle flux rates than
heavy ion experiments.

	The DOT was mounted on an X-Y-Z stage in front
	100x lens that produces a spot diameter of approxima
	1 μm at full-width half-maximum (FWHM). The X
	stage can be moved in steps of 0.1 µm for accu
	determination of SEE-sensitive regions in front of
	focused beam. An illuminator, together with a cha
	coupled device (CCD) camera and monitor, were use
1	image the area of interest thereby facilitating accu
1	positioning of the device in the beam. The pulse en
	was varied in a continuous manner using a polarizer/
	waveplate combination and the energy was monitored
i	splitting off a portion of the beam and directing it
	calibrated energy meter.
	Calibrated energy meter.

## **Test Results** Overview

given energy (i.e. 200 MeV, etc).

investigators				
Principal Investigator (PI)	Abbreviation			
Melanie D. Berg	MB			
Michael J. Campola	MJC			
Megan C. Casey	MCC			
Dakai Chen	DC			
Jean-Marie Lauenstein	JML			
Edward (Ted) Wilcox	TW			
Edward Wyrwas	EW			

# **Table IV: Abbreviations**

	LET linear an argu transfer (Ma) (sem²/ma)
	LET = linear energy transfer (MeV•cm²/mg)
	LET <sub>th</sub> = linear energy transfer threshold (the
	maximum LET value at which no effect was
	observed at an effective fluence of
	1x10 <sup>7</sup> particles/cm <sup>2</sup> – in MeV•cm <sup>2</sup> /mg)
	< = SEE observed at lowest tested LET
	> = no SEE observed at highest tested LET
	$\sigma$ = cross section (cm <sup>2</sup> /device, unless specified as
	cm²/bit)
	$\sigma_{\text{maxm}}$ = cross section at maximum measured LET
	(cm²/device, unless specified as cm²/bit)
	ADC = analog-to-digital converter
	CMOS = complementary metal oxide
	semiconductor
	DDR = double data rate
	DUT = device under test

# energy at a fixed V<sub>as</sub> (gate-to-source voltage).

LET = linear energy transfer (MeV•cm²/mg) LET <sub>th</sub> = linear energy transfer threshold (the maximum LET value at which no effect was observed at an effective fluence of 1x10 <sup>7</sup> particles/cm² – in MeV•cm²/mg) < = SEE observed at lowest tested LET > = no SEE observed at highest tested LET σ = cross section (cm²/device, unless specified as cm²/bit)	
σ <sub>maxm</sub> = cross section at maximum measured LET (cm²/device, unless specified as cm²/bit) ADC = analog-to-digital converter	
CMOS = complementary metal oxide semiconductor	
DDD devible data rate	

CMOS = complementary metal oxide
semiconductor
DDR = double data rate
DUT = device under test
ECC = error correcting code
GE = General Electric
H = heavy ion test
ID# = identification number
IDSS = drain-source leakage current
lout = output current
LBNL = Lawrence Berkeley National La

# 3) SEE Testing - Pulsed Laser Facility Testing:

# Table III: List of Principal

ET = linear energy transfer (MeV•cm²/mg)	
ET <sub>th</sub> = linear energy transfer threshold (the	
maximum LET value at which no effect was	
observed at an effective fluence of	
1x10 <sup>7</sup> particles/cm <sup>2</sup> – in MeV•cm <sup>2</sup> /mg)	
= SEE observed at lowest tested LET	
= no SEE observed at highest tested LET	
= cross section (cm²/device, unless specified as	
cm <sup>2</sup> /bit)	
maxm = cross section at maximum measured LET	
(cm <sup>2</sup> /device, unless specified as cm <sup>2</sup> /bit)	
DC = analog-to-digital converter	
MOS = complementary metal oxide	
semiconductor	

DO - analog to aightal conventor
MOS = complementary metal oxide
semiconductor
DR = double data rate
UT = device under test
CC = error correcting code
E = General Electric
= heavy ion test
D# = identification number
DSS = drain-source leakage current
out = output current

1200 = drain source rearrage current
lout = output current
LBNL = Lawrence Berkeley National Laboratory
LDC = lot date code
LPP = low power plus
MLC = multi-level cell
MOSFET = metal-oxide-semiconductor field-effect
transistar

SFET = metal-oxide-semiconductor field-effect	
transistor	
IC = Northwestern Medicine Chicago Proton	
Center	
L = Naval Research Laboratory	
M = phase change memory	
= principal investigator	

REAG = Radiation Effects and Analysis Group RF = radio frequency SBU = single-bit upset SDRAM = synchronous dynamic random access

SEGR = single event gate rupture SEL = single event latchup SET = single event transient SEU = single event upset

TAMU = Texas A&M University Cyclotron Facility DMOS = vertical double-diffused metal oxide semiconductor ns = drain-source voltage /<sub>GS</sub> = gate-source voltage

ET = linear energy transfer (MeV•cm²/mg) ET <sub>th</sub> = linear energy transfer threshold (the maximum LET value at which no effect was observed at an effective fluence of 1x10 <sup>7</sup> particles/cm² – in MeV•cm²/mg) = SEE observed at lowest tested LET = no SEE observed at highest tested LET	
= cross section (cm²/device, unless specified as cm²/bit)	
naxm = cross section at maximum measured LET (cm²/device, unless specified as cm²/bit)	
DC = analog-to-digital converter	
MOS = complementary metal oxide semiconductor	
DD davida data sata	1

CMOS = complementary metal oxide	
semiconductor	
DDR = double data rate	
DUT = device under test	
ECC = error correcting code	
GE = General Electric	
H = heavy ion test	
ID# = identification number	
IDSS = drain-source leakage current	
lout = output current	

it – output ourroint	
NL = Lawrence Berkeley National Laboratory	
C = lot date code	
P = low power plus	
_C = multi-level cell	
OSFET = metal-oxide-semiconductor field-effect	
transistor	
MC = Northwestern Medicine Chicago Proton	

SEB = single event burnout SEE = single event effect

V<sub>th</sub> = gate threshold voltage

investigator	3
Principal Investigator (PI)	Abbreviation
Melanie D. Berg	MB
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Megan C. Casey	MCC
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	<u> </u>

ET = linear energy transfer (MeV•cm²/mg)  ET <sub>th</sub> = linear energy transfer threshold (the maximum LET value at which no effect was observed at an effective fluence of 1x10 <sup>7</sup> particles/cm² – in MeV•cm²/mg)  = SEE observed at lowest tested LET  = no SEE observed at highest tested LET  = cross section (cm²/device, unless specified as cm²/bit)	
naxm = cross section at maximum measured LET (cm²/device, unless specified as cm²/bit)  DC = analog-to-digital converter  MOS = complementary metal oxide	

(cm /acvice, amess specified as cm /bit)
ADC = analog-to-digital converter
CMOS = complementary metal oxide
semiconductor
DDR = double data rate
DUT = device under test
ECC = error correcting code
GE = General Electric
H = heavy ion test
ID# = identification number
IDSS - drain-source leakage current

# = identification number	İ
SS = drain-source leakage current	
ut = output current	j
BNL = Lawrence Berkeley National Laboratory	İ
DC = lot date code	
PP = low power plus	İ
LC = multi-level cell	İ
OSFET = metal-oxide-semiconductor field-effect	İ

SOC = system on chip

## **Memory Devices:** EL LET<sub>th</sub> > 34.9; MT46V128M8P DDR SDRAM CMOS SEFI LET th < 1.3; SEFI $\sigma \sim 5 \times 10^{-4} \text{ cm}^2 [20]$ MT29F4G08ABADAWF SEU σ (MLC mode) 1.8 x 10<sup>-10</sup> cm<sup>-2</sup>/bit MT29F1T08CMHBBJ4 |SEFI σ ~ 2x10<sup>-4</sup> cm<sup>-2</sup> EL LET<sub>th</sub> > 58.78.[2]June) SEU $\sigma \sim 1.6 \times 10^{-10} \text{cm}^{-2}/\text{bit}$ ; MT29F512G08AUCBBH8 SEFI LET<sub>th</sub> 1.78 < x < 3.49; SEFI $\sigma \sim 6.93 \times 10^{-10} \text{ cm}^2$ , Upset mode has elevated current **Power Transistors:**

(Facility/Year/

LET in MeV•cm<sup>2</sup>/ma

						(LET = 21) at full rated -50 $V_{DS}$ .		
SQJ431EP-TI-GE3	Vishay	(16-025)	MOSFET	p-channel trench	H: (LBNL2017Apr) JML/MCC	886 MeV Kr (LET=31) part-part variability with SEGR at -150 V <sub>DS</sub> . No failures with 659 MeV Cu (LET = 21) at full rated -200 V <sub>DS</sub> . [23]	0 V <sub>GS</sub>	4
Si7414DN-T1-E3	Vishay	(16-030)	MOSFET	n-channel trench	H: (TAMU2017Mar; LBNL2017Apr) JML/MCC	SEB, with part-part variability of threshold. 400 MeV Ar (LET=9.7): last pass/first fail V <sub>DS</sub> =51/57V; 659 MeV & 785 MeV Cu (LET=20&21): 36/39V; 886 MeV & 993 MeV Kr (LET=28&31): 39/42V. Dose effects at all biases including Vth and I <sub>DSS</sub> degradation at 0 V <sub>DS</sub> . [23]	0 V <sub>GS</sub>	11
SQS460EN-T1GE3	Vishay	(17-005)	MOSFET	n-channel trench	H: (TAMU2017Mar; LBNL2017Apr) JML/MCC	SEB, with part-part variability of threshold. 659 MeV & 785 MeV Cu (LET=20&21): last pass/first fail V <sub>DS</sub> =36/39V; 886 MeV & 993 MeV Kr (LET=28&31): 39/42V. Dose effects at all biases including Vth and I <sub>DSS</sub> degradation at 0 V <sub>DS</sub> . [23]	0 V <sub>GS</sub>	21
/TFS5116PLWFTAG	ON Semiconductor	(17-006)	MOSFET	p-channel	H: (TAMU2017Mar; LBNL2017Apr) JML/MCC	886 MeV Kr (LET=31) part-part variability with SEGR at -52 V <sub>DS</sub> .  No failures with 659 MeV Cu (LET = 21) at full rated -60 V <sub>DS</sub> .[23]	0 V <sub>GS</sub>	6
CGHV59350F	CREE	C32958S, C32956S, D1312S (17-065)	JFET	GaN HEMT	H: (TAMU2017Jun; 2017Oct) JML	Static and RF-mode tests reveal significant part-part variability: additional testing scheduled. Contact PI.	Static: -5 V <sub>GS</sub> ; RF: 50 V <sub>DS</sub>	7
ngineering Samples,	GE	(17-084)	MOSFET		H: (TAMU2017Jun)	Contact PI.	0 V <sub>GS</sub>	84

various	GE	(17-084)	MOSFET	VDMOS	JML	Contact PI.	0 V <sub>GS</sub>	84
A Devices:								
G150-CB1657PROTO	Microsemi	1638 (17-003)	FPGA	65 nm CMOS	IMR	Flip-Flops: 1 <seu let<sub="">th &lt;1.8 Configuration: SEU LET<sub>th</sub> &gt; 60 SEL LET<sub>th</sub> &gt; 60 [24]</seu>	nominal	1
(U040-1LFFVA1156I Kintex-UltraScale	Xilinx	1509 (15-061)	FPGA	FPGA (20 nm planar)	TAMU2017Mar;	Configuration bits: SEU LET <sub>th</sub> <0.07; SEFI LET <sub>th</sub> <1.8 SEL LET <sub>th</sub> > 50 [25]	nominal	2 (1 each test date)
ellaneous Devic	es:							
)2G-P4-6152-KR	nVidia	2016 (17-039)	Processor	14 nm FinFET	Drotono:	200 MeV protons, SEFI $\sigma \sim 1.42 \times 10^{-10} \text{ cm}^2$ , SEU $\sigma \sim 1.37 \times 10^{-10} \text{ cm}^2$ . Upset	12 VDC	1

12' ( 111' 🔿 1	VIIIIIX	(45 004)	IFGA	(2011111	TABALIO047D \ NAD		Hollinai			
Kintex-UltraScale		(15-061)		planar)	TAMU2017Dec) MB	SEL LET <sub>th</sub> > 50 [25]		test date)		BZX8
cellaneous Devic	es:								-	
02G-P4-6152-KR	nVidia	2016 (17-039)	Processor	14 nm FinFET CMOS	(MGH2017Apr) EW	200 MeV protons, SEFI $\sigma \sim 1.42 \times 10^{-10} \text{ cm}^2$ , SEU $\sigma \sim 1.37 \times 10^{-10} \text{ cm}^2$ . Upset modes include SEFI, pixel artifacts and clock tree failure. [26]	12 VDC	1		BZX8
ngineering Samples	NASA GRC	(17-066)	Ring Oscillator	SiC	,	no catastrophic SEE up to 2006- MeV Au (LET(Si) = 87)	+/- 28 V	3		BZX8
DRV102	Texas Instruments	1440 (16-037)	PWM Solenoid/ Valve Drive	CMOS	H: (TAMU2017Jun) MJC	SEL LET <sub>th</sub> > 79; SET LET <sub>th</sub> < 13; SET σ ~ 5x10 <sup>-3</sup> cm <sup>2</sup> Observed SETs included: 1) Changes in the pulse-width on the output, both shortening and lengthening of the duty cycle, 2) False triggers on the thermal shutdown flag, and 3) Altering of the 24kHz output frequency for no more than one clock cycle. [27]	28 V	6	_	BZX84
AD654	Analog Devices	0630 (16-036)	Op-Amp	Bipolar	H: (LBNL2017Apr) MJC	SEL LET <sub>th</sub> > 58.78; LET <sub>th</sub> < SET 2.19 [28]	1 and 5 V	4	L	
KSW-2-46+	MiniCircuits	(17-004)	RF Switch	CMOS	Laser:	No destructive events observed at a laser energy of ~64 nJ. Worst case transients had an	-5 V	2		

Low Dropout

Voltage

(17-062)

amplitude of approximately 1 V and

duration of 10 ns.

(TAMU2017Oct) No destructive events observed for

BAS70-05-7-F NSR0140P2T5G CMPD2003 TI BAS21,215 BAS21-E3-08 No failures or degradation observed at 100% of reverse voltage when irradiated No failures or degradation observed at 100% of reverse voltage when irradiated to 1232 MeV Xe (LET = 58.8). Diode 100% of reverse voltage when irradiated No failures or degradation observed at 100% of reverse voltage when irradiated No failures or degradation observed at 100% of reverse voltage when irradiated No failures or degradation observed at BAR64-05 E6327 o to 1232 MeV Xe (LET = 58.8). No failures or degradation observed at

> 58.8), but all post-irradiation electrical parameter measurements remained within No failures or degradation observed at Diode 100% of reverse voltage when irradiated Degradation was observed during beam run when biased at 100% of Zener voltage 1: (LBNL2017Apr) and irradiated with 1232 MeV Xe (LET = (17-034) Diode parameter measurements remained within No failures or degradation observed at 100% of reverse voltage when irradiated o to 1232 MeV Xe (LET = 58.). Degradation was observed during beam run when biased at 100% of Zener voltage (17-036) Diode 58.8), but all post-irradiation electrical parameter measurements remained within atastrophic failures observed during Super H: (LBNL2017Apr) | beam run while biased at 100% of reverse | 200

100% of reverse voltage when irradiated

No failures or degradation observed at

No failures or degradation observed at

100% of reverse voltage when irradiated

No failures or degradation observed at

No failures or degradation observed at

p to 1232 MeV Xe (LET = 58.8).

100% of reverse voltage when irradiated

Degradation was observed during beam

run when biased at 100% of Zener voltage

voltage when irradiated with 1233 MeV Xe

100% of reverse voltage when irradiated

As in our past workshop compendia of NASA Goddard Space Flight Center (GSFC) test results, each DUT has a detailed test report available online at radhome.gsfc.nasa.gov [16] and nepp.nasa.gov [17]. The Test Results and Discussion section contains summaries of testing performed on a selection of featured parts.

## **Test Results and Discussion**

### Avalanche Technology's AS008MA12A-C1SC SPnVSRAM

The Avalanche Technology AS008MA12A-C1SC is an 8-Mb serial nonvolatile memory that uses Avalanche's proprietary pMTJ STT-MRAM technology. Samples in a 16-pin SOIC package were provided to NASAtesting program. Testing was conducted by NASA GSFC at the Texas A&M University Cyclotron Facility (TAMU) with a typical set of heavy ions (Table I) obtained with the 15-MeV/amu beam tune.

Table III: Heavy Ion Beams used at TAMU for AS008MA12A-C1SC SPnVSRAM

lon	Beam Energy (MeV/amu)	Energy (MeV)	Range in Si (µm)	Nominal LET in Si (MeV- cm²/mg)
14N	15	210	428	1.30
<sup>63</sup> Cu	15	944	172	19.6
<sup>109</sup> Ag	15	1634	156	42.2
<sup>197</sup> Au	15	2954	155	85.4

commercially-available ARM Cortex-M0 microcontroller board (Fig. 1), with commands from a laptop PC over a USB link



Fig. 1. Microcontroller test board and decapsulated memory device ready for irradiation.

Several test modes were used to identify different single-event effects Static memory testing (both powered and un-powered during irradiation) did not result in any memory cell upsets up to and including a normal-incidence LET of 85.4 MeV•cm<sup>2</sup>/mg, and a 45-degree irradiation with an effective LET of 120.7 MeV•cm²/mg. Tests were completed to a fluence greater than 1x10<sup>7</sup>/cm<sup>2</sup>.

Tests for single-event latchup (SEL) were conducted at nominal voltage (1.8 V) and elevated voltage (2.0 V) at room temperature, with a fluence of at least 1x10<sup>7</sup>/cm<sup>2</sup>. No single-event latchup events were observed at the highest LET tested (85.4 MeV•cm<sup>2</sup>/mg). No parts were permanently damaged or degraded during heavy-ion testing.

Single-event functional interrupts (SEFI) were observed at an LET of 1.84 MeV•cm<sup>2</sup>/mg and greater (Fig. 2). No SEFI were observed at an LET of 1.3 MeV•cm<sup>2</sup>/mg after a fluence of 5.2x10<sup>7</sup>/cm<sup>2</sup>.

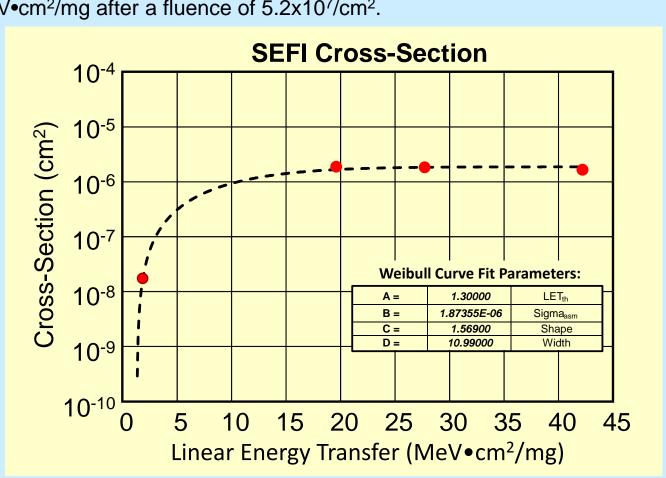
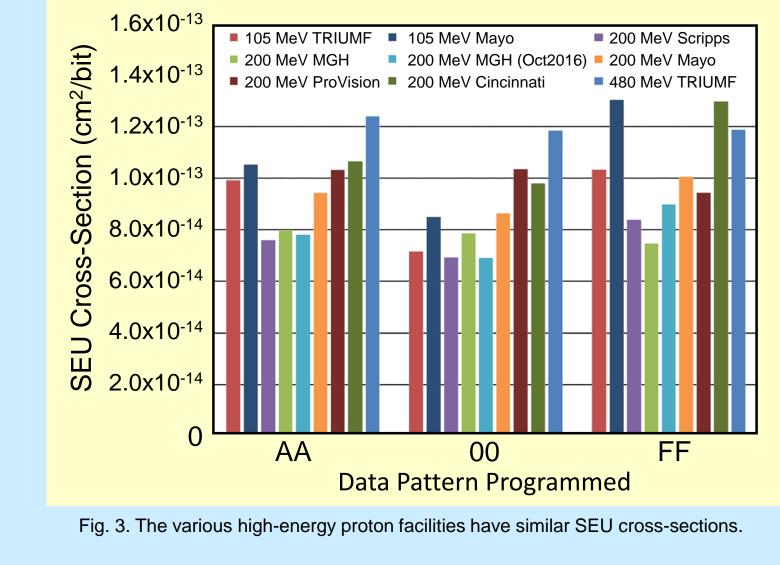


Fig. 2. AS008MA12A-C1SC SPnVSRAM partial-SEFI cross section as a function of LET.

SEFIs presented primarily as large numbers of memory errors, typically present in several, but not all, of the memory's blocks (so-called "partial" SEFI). These errors in the control circuitry were cleared with a power cycle, although no re-programming was necessary (i.e. the underlying memory array was not upset). A SEFI that broke communication with the device was observed at an LET of 42.2 MeV•cm²/mg and a cross-section of 3.2x10<sup>-8</sup>cm² The effect was again observed at an LET of 85.4 MeV•cm²/mg, but other runs were completed to 1x10<sup>7</sup>/cm<sup>2</sup> without any loss-of-communication SEFIs, suggesting an extremely low sensitivity to these events. [19]

evaluating the proton beam offerings at each high-energy facility we have Proton Therapy (MGH), Tri-University Meson Facility (TRIUMF) Northwestern Medicine Chicago Proton Center, California Protons Cancer Therapy Center (formerly Scripps Proton Therapy Center), Mayo Clinic, ProVision Center for Proton Therapy, and the Proton Therapy Center at Cincinnati Children's Hospital. For most of these facilities, the proton energy were tested, and 105 MeV was tested in addition to 200 MeV at the Mayo

Fig. 3 shows the comparison of the measured SEU cross-sections fo each of the facilities. There was no major difference between facilities, so all are suitable options for high-energy protons.



Summary

We have presented current data from SEE testing on a variety of mainly commercial devices. It is the authors' recommendation that these data be used with caution. We also highly recommend that lot testing be performed on any suspect or commercial device.

## Acknowledgment

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Research Laboratory for their excellent support of the laser testing.

## References

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